

VERIFICATION OF THE BAZIN WEIR FORMULA BY HYDRO- CHEMICAL GAUGINGS

By
FLOYD A. NAGLER

1917



A dissertation submitted in partial fulfillment of the requirements for the degree of "Doctor of Philosophy" in the University of Michigan.

Diss. Ann Arbor
1917.

AMERICAN SOCIETY OF CIVIL ENGINEERS

INSTITUTED 1852

PAPERS AND DISCUSSIONS

This Society is not responsible for any statement made or opinion expressed
in its publications.

VERIFICATION OF THE BAZIN WEIR FORMULA
BY HYDRO-CHEMICAL GAUGINGS.

BY FLOYD A. NAGLER, JUN. AM. SOC. C. E.

TO BE PRESENTED MARCH 6TH, 1918.

SYNOPSIS.

This paper presents the results of 23 experiments on a standard Bazin weir, 3.72 ft. high and 6.56 ft. wide. The experiments were carried on in a flume built for the University of Michigan at the Argo Spillway, Ann Arbor, Mich.

The water was measured hydro-chemically, according to the methods recommended by B. F. Groat, M. Am. Soc. C. E., in his paper entitled "Chemi-Hydrometry and Its Application to the Precise Testing of Hydro-Electric Generators."*

Tests were made on heads as high as 4 ft. on the weir, thus extending the application of the weir formulas more than 100 per cent.

This paper describes briefly the method of hydro-chemical and weir gauging used in the experiments.

INTRODUCTION.

Volumetric experiments on the flow of water over sharp-crested weirs have been performed for only a comparatively small range in head on the weir. M. Bazin's experiments cover a range in head from 0.194 to 1.780 ft.; those of the late J. B. Francis, Past-President, Am.

NOTE.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.

* *Transactions*, Am. Soc. C. E., Vol. LXXX, p. 951.

Soc. C. E., are included between 0.736 and 1.060 ft.; and the experiments of Messrs. Fteley and Stearns are between 0.0735 and 1.6038 ft.

These experimenters were unable to use higher heads due to the fact that their volumetric measuring basins filled too rapidly with the larger quantities of water which flowed over the weir at high heads. Nevertheless, these few experiments, within so small a range in head, were used by each experimenter in evaluating the coefficients for the standard weir formulas which bear their names.

For lack of a better basis of computation, engineers have been continually forced to apply the Bazin, Francis, and Fteley and Stearns formulas in the solution of problems involving heads on the weir many times that of the maximum on which any of these formulas are based.

Considerable might be written on the discrepancies (of as much as 3%) which exist between the three formulas for some heads of less than 2 ft.; but nothing is known of the possible differences which may exist for higher heads. Without further experiments, covering a wider range in head, these formulas cannot be applied with security in the computation of discharge in case the head falls outside those limits on which each respective formula is based.

Within the past decade the hydro-chemical method of gauging large quantities of water, originally used by some Swiss engineers, has been introduced into the United States. In 1914 Mr. Groat applied this method with considerable accuracy in testing hydro-electric generators, where quantities of water as large as 1 500 cu. ft. per sec. had to be measured. He published the results of these tests, together with an exhaustive treatment of the theory of salt-solution gauging, in his paper, "Chemi-Hydrometry and Its Application to the Precise Testing of Hydro-Electric Generators". In this paper Mr. Groat describes a method of "salt-solution gauging" for which he claims an accuracy that could only be attained by the most precise volumetric measurements. This method might easily be applied in gauging the flow of water over a weir, thus checking the existing volumetric experiments and extending the present experimental data to higher heads.

Contemplating the performance of such a set of experiments, an experimental flume was constructed at the Argo Spillway, Ann Arbor, Mich., for the University of Michigan, by the Detroit Edison Company. In the construction of this flume, it was decided to duplicate the conditions of the Bazin experiments, with additional capacity

sufficient to obtain heads on the weir (3.72 ft. high and 6.56 ft. long) as high as 4 ft. The proposed experiments could then be compared with an accepted standard weir formula and its basic experiments.

The experiments were performed between March 24th and May 2d, 1917.

BAZIN'S EXPERIMENTS AND FORMULA.

Bazin began his extensive weir experiments in 1886 on the Canal de Bourgogne, near Dijon, France. The weirs were constructed in a channel 6.56 ft. (2 m.) wide. Contractions were suppressed. The crest itself was made of an iron plate. Of these experiments 67 were performed on a weir 3.72 ft. high and 6.56 ft. wide, including heads up to 1.012 ft.; 38 on a weir 3.27 ft. high and 3.28 ft. long, with heads up to 1.34 ft.; and 48 on a weir 3.297 ft. high and 1.64 ft. long, including heads up to 1.780 ft. Having calibrated his standard weir within at least 1% by volumetric measurements, M. Bazin proceeded to perform experiments on weirs of different heights at places down stream in the same channel. From the results of these observations, he evaluated the coefficients for his formula. If H is the measured head on the weir, p the height of the weir, and L the length of the weir crest, then Q , the discharge in cubic feet per second, is expressed as follows:

$$Q = \left(0.405 + \frac{0.00984}{H} \right) \left(1 + 0.55 \frac{H^2}{(p + H)} \right) L H \sqrt{2gH}$$

If the salt-solution method of gauging in the proposed experiments checks the volumetric measurements of flow over the weir throughout the range of the Bazin experiments, there is then established a basis for measuring accurately the water flowing over the weir, and the range of application of the weir formula becomes extended.

CHEMI-HYDROMETRY.

The process of measuring the quantity of a liquid by observing the dilution that a solution of some chemical undergoes in being thoroughly mixed with that liquid, has been called "chemi-hydrometry."

For example, let 10 lb. of salt be thoroughly dissolved in a tank of water. If, on chemical analysis, it is found that each cubic foot of this water contains 1 lb. of salt, the volume of water in the tank is equal to the ratio of dilution of the salt, or 10 cu. ft. Or, suppose that a salt solution is introduced into a flowing stream at the rate of 1 cu. ft. per sec. If this salt solution contains 10 lb. of salt per cubic foot, and

it is found that each cubic foot of the flowing water, after being mixed with the salt solution, contains 1 lb. of salt, then the rate of flow of the stream is represented by the "ratio of dilution" of the salt solution, multiplied by the rate at which that solution is introduced into the stream; or, in this case, 10 cu. ft. per sec.

These examples give the essence of the theory of hydro-chemical gauging. In practice, however, other factors enter, which produce many complications. For a full treatment of errors and complications which arise, reference should be made to the paper by Mr. Groat previously referred to. The following brief treatise on the subject is offered in order to save the reader the labor of reading and mastering Mr. Groat's voluminous paper, since only that part of the theory is presented which will be necessary for an understanding of the methods used in these experiments. The symbols and definitions used by Mr. Groat have been adopted throughout.

In most cases the normal water contains an initial quantity of salt in solution; this must be taken into consideration, in order to make a correct gauging. Corrections must also be applied in comparing solutions of unlike temperatures. In some cases, cognizance must be taken of the fact that, when two solutions with different percentages of salt in solution are mixed, the total volume is less than the sum of the volumes of the two initial constituent solutions. This shrinkage in volume is taken into consideration by applying a coefficient, k , to the stronger solution, such that the volume of the weaker solution plus the volume of the stronger solution multiplied by k is equal to the volume of the resultant mixture.

The method of "special dilutions" and "balanced evaporations" was adopted in making the salt analysis in these tests. This method simply implies that a special dilution of the salt solution sample with the normal water sample is made in the laboratory. Effort is made to have the "ratio of dilution" of this special dilution approximate the estimated ratio of dilution during the test. This special dilution receives the same method of treatment in the laboratory as the dosed water samples.

Definitions and Equations.—The "ratio of mixture" is the ratio of the quantity of the weaker of two solutions to the quantity of the other solution with which it is mixed. It is represented by r .

The "ratio of dilution" is the ratio of the quantity resulting from the mixture of two salt solutions of different percentages to the quantity having the higher percentage. It is represented by R .

When a solution is referred to as "being of a certain percentage" it is meant that this percentage of the total weight of the solution is dry salt. It is represented by p .

By "concentration of solution" is meant the weight of chemical in solution per unit of volume. It is represented by c .

Then, let Q_1 = the quantity of water flowing in the stream;

q = the rate of discharge of the salt solution;

Q_2 = the quantity of water flowing in the stream after the introduction of the salt solution;

k = the coefficient of shrinkage of the salt solution; and

c_1, c, c_2 = the concentrations of the normal water, salt solution, and dosed flume water, respectively.

If all the solutions are at the same temperature; or, if originally at different temperatures, temperature corrections have been previously applied, then

$Q_1 c_1$ = the weight of salt in the normal water; $q c$ = the weight of salt in the salt solution; and $Q_2 c_2$ = the weight of salt in the mixture.

Hence, $Q_1 c_1 + q c = Q_2 c_2$(1)

Also, by definition, $Q_1 + k q = Q_2$(2)

Likewise, $\frac{Q_1}{q} = r$

and, $\frac{Q_2}{q} = R$

By substitution in Equation (1) $rc_1 + c = Rc_2$(3)

By substitution in Equation (2) $r + k = R$(4)

By substituting Equation (4) in Equation (3), we obtain,

$$rc_1 + c = rc_2 + kc_2$$

Whence, solving for r , we obtain,

$$r = \frac{c - kc_2}{c_2 - c_1} \dots\dots\dots(5)$$

Also, solving for c_1 , we obtain,

$$c_1 = \frac{rc_2 + kc_2 - c}{r} \dots\dots\dots(6)$$

Equation (5) may be applied when the method of special dilutions is not used. It is applicable when the normal water, dosed water, and salt-solution sample are analyzed directly.

However, let a special dilution be made up in the laboratory, using the actual salt-solution sample with the concentration, c , and the normal pond water with the concentration, c_1 . The ratios of mixture and dilution should approximate r and R , respectively, but actually have values of r' and R' . The final dilution has a concentration c'_2 , approximating c_2 . Then, by analogy, we may write, from Equation (6),

$$c_1 = \frac{r'c'_2 + kc'_2 - c}{r'}$$

In this equation, r must approximate r' so closely that the coefficient of shrinkage is the same for both dilutions.

Equations (6) and (7), however, may be placed equal to each other.

$$\frac{r'c'_2 + kc'_2 - c}{r'} = \frac{rc_2 + kc_2 - c}{r}$$

Solving for r , we obtain

$$r = \frac{r'}{\frac{c - r'c_2 - r'c'_2 - kc'_2}{c - kc_2}}$$

By analogy, from Equation (4), however, $r' = R' - k$. Substituting this value of r' in the denominator of the previous expression, we obtain

$$r = \frac{r'}{1 + R' \frac{c_2 - c'_2}{c - kc_2}}$$

Thus,
$$Q_1 = qr = q \frac{r'}{1 + R' \frac{c_2 - c'_2}{c - kc_2}} \dots \dots \dots (8)$$

This equation is of practical application. It should be observed that c_1 has been eliminated; hence, it is unnecessary to analyze the normal pond water for its saline content. It has been stated that the use of this equation requires the previous correction of the volume of every solution handled throughout the entire laboratory process, reducing every sample analyzed in each experiment to some common temperature.

The reagent used in salt analysis is silver nitrate. This chemical is dissolved in distilled water in some standard proportions. Then a

measured quantity of this silver nitrate solution is used, sufficient to neutralize exactly all the salt in a given sample. The molecular weight of silver nitrate is 170; that of sodium chloride (common salt) is 58.5.

Hence, 1 gramme of silver nitrate will neutralize $\frac{58.5}{170} = 0.3441$ grammes of salt. Thus, if the quantity of anhydrous silver nitrate contained in the silver nitrate solution used in a titration is known, the quantity of anhydrous salt contained in the sample is 0.3441 times this quantity.

If all titrations require about the same quantity of silver nitrate solution, and all samples, prepared for analysis, are of the same character and volume, and if the same quantity of indicator is used to indicate the end point of the reaction for each sample, then, for practical purposes, we may write,

$$c = \alpha t,$$

where t is the volume of the silver nitrate solution required to titrate a unit volume of the sample, and α is a constant dependent on the concentration of the standard silver nitrate solution, and the actual equivalent between the silver nitrate and the sodium chloride. Hence, we may write with practically (not theoretically) no error,

$$Q_1 = q r = q \frac{r'}{1 + R' \frac{t_2 - t'_2}{t - k t_2}} \dots \dots \dots (9)$$

Thus, if silver nitrate of the same strength is used for all titrations in a single experiment, it becomes unnecessary to determine the actual salt content of the sample or the exact concentration of the silver nitrate solution. The values of t'_2 and t_2 have such a relation in the equation that when t'_2 approximates t_2 , and there is then the same relative error in both titrations, this error has no effect on the practical value of r .

Therefore, in order to make a salt-solution test, three samples must be provided:

- (1) A sample of the salt solution;
- (2) A sample of the normal pond water; and,
- (3) A sample of the dosed flume water.

The equation also designates that q , the rate of dosing, must be observed; and the laboratory process further involves the observation

of the temperatures of all solutions and the calibration of all flasks and pipettes, in order that r' and R' may be calculated with accuracy.

DESCRIPTION OF TESTING PLANT.

Testing Flume.—The flume in which these experiments were performed was built in September, 1916, by the Detroit Edison Company. Connecting with two of the flood-gates at the Argo Spillway, it extended 143 ft. down stream.

Figs. 1 to 4 show the nature of the design and the construction of the flume.

The first 40 ft. of the flume was built $8\frac{1}{2}$ ft. wide and 9 ft. deep. It then became necessary to divert it in the direction assumed by the natural flow of the river, and the remaining 103 ft. was made 6.56 ft. (2 m.) wide, the width of the Bazin channel. The lining was of 2-in., matched yellow pine, with driven splines uniting every board. No effort was made to caulk these joints or fill them with white lead. After the flume had been filled with water for three days, allowing the lining to soak and expand, there was no visible leakage at any point.

Figs. 5, 6, and 7 show the flume in process of construction, and Fig. 9 is reproduced from a photograph of the finished structure.

The quantity of water entering the flume was regulated by lowering or raising the flood-gates at the spillway. The salt solution was introduced under pressure into a sprinkling system in the orifices of these gates. Due to the fact that the water entered the flume at a very high velocity, it first became necessary to lower this abnormal velocity and distribute it uniformly over the entire flume section. This was accomplished by constructing a submerged weir $3\frac{1}{2}$ ft. high across the flume at a point 16 ft. down stream from the gates. In striking this obstruction at a high velocity, the water was thrown into a great commotion, passing over the weir with a fair velocity distribution, regardless of the turbulence. This weir proved an excellent mixer for the salt solution, securing practically its uniform distribution throughout the entire flume section.

As the water passed around the bend in the flume, the velocity at the outside was observed to be perceptibly higher than that on the inside. This abnormal condition was remedied by placing sets of horizontal and vertical baffles at a point 10 ft. below the bend. The

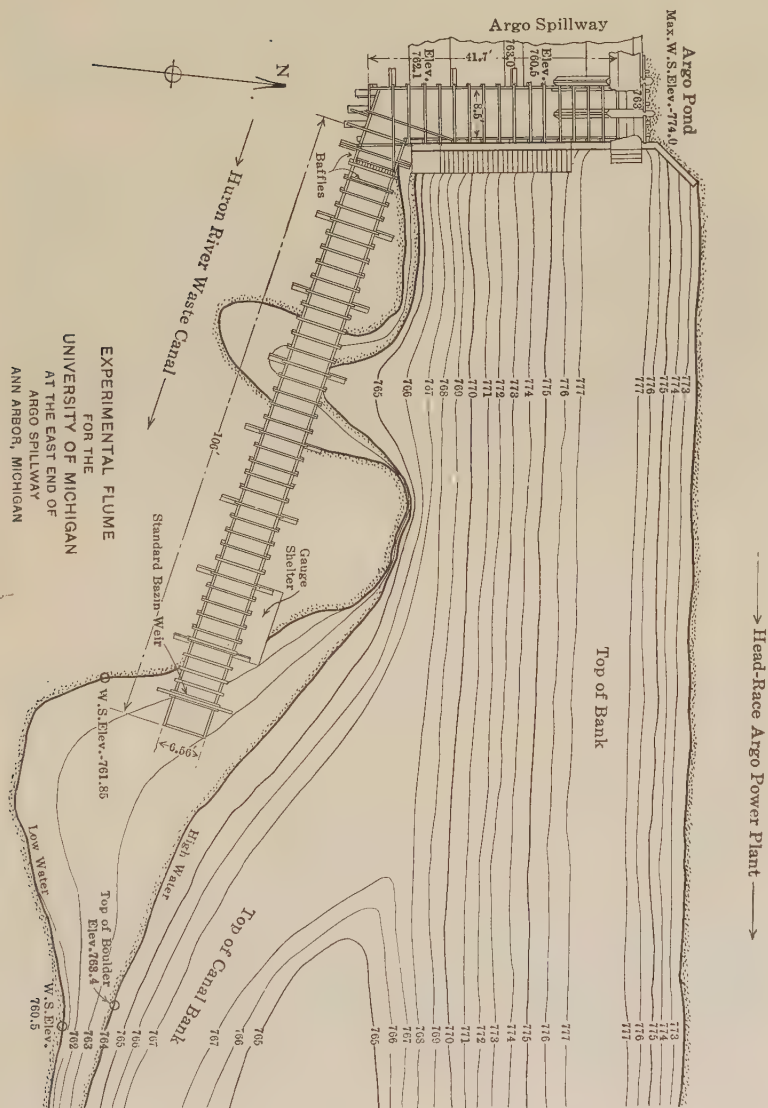


FIG. 1.

baffles were constructed of 2-in. yellow pine boards, swinging on an eccentric longitudinal axis. By closing the vertical baffles at the right of the flume, a uniform distribution of velocities was again secured. Fig. 11 exhibits velocity contours taken at a point 25 ft. above the weir. These contours were obtained with an Ott current meter operating on a metal rod when there was a head of about 3 ft. on the weir.

Two floating railroad ties were placed across the flume about 28 ft. above the weir. These were efficient in reducing the small oscillatory wave motion of the water in the channel of approach.

The Weir.—The weir was built up of 4-in. timbers, as shown in the section on Fig. 4. The crest was formed by a $\frac{1}{8}$ -in. brass strip, inserted at one edge of, and flush with one face of, a 7 by $\frac{3}{8}$ -in. plate of cold-rolled steel. The brass strip was soldered and screwed to the steel plate, all recesses in the countersunk holes being filled with solder. The back face of the plate and the upper edge of the brass was then planed and finished absolutely true. This left a sharp right-angled knife-edge on the up-stream corner of the crest. The object of the brass strip was to produce a crest which would not be subject to corrosion, thus preventing the introduction of error in the weir discharge from this source. The whole plate was inserted flush with the up-stream face of the wooden timbers, and fastened to them by bolts the heads of which were countersunk in the back of the steel plate. The crest was set at an elevation of 3.72 ft. above the bottom of the flume.

Four $\frac{3}{4}$ -in. bolts, 40 in. long, bound the weir timbers to the bottom of the flume. By loosening or tightening the nuts on these bolts, on either side, the weir crest was maintained absolutely level throughout the experiments.

The sides of the flume extended 6 ft. beyond the weir, but the floor extended no farther than the weir. This feature insured abundant aeration for the nappe from underneath.

The frame of the flume at the weir section was made of quadruple strength. All joints were bolted, and great care was exercised in plumbing the side posts. The timbers under the flume, at this point, rested on 4 ft. of concrete. The side posts of the frame extended for 3 ft. into the concrete. This produced a very rigid and permanent frame at the weir section. The construction is clearly shown in Fig. 4 and the erection of the frame is shown in Fig. 6.



FIG. 2.—UNIVERSITY OF MICHIGAN EXPERIMENTAL FLUME.



FIG. 3.—UNIVERSITY OF MICHIGAN EXPERIMENTAL FLUME.

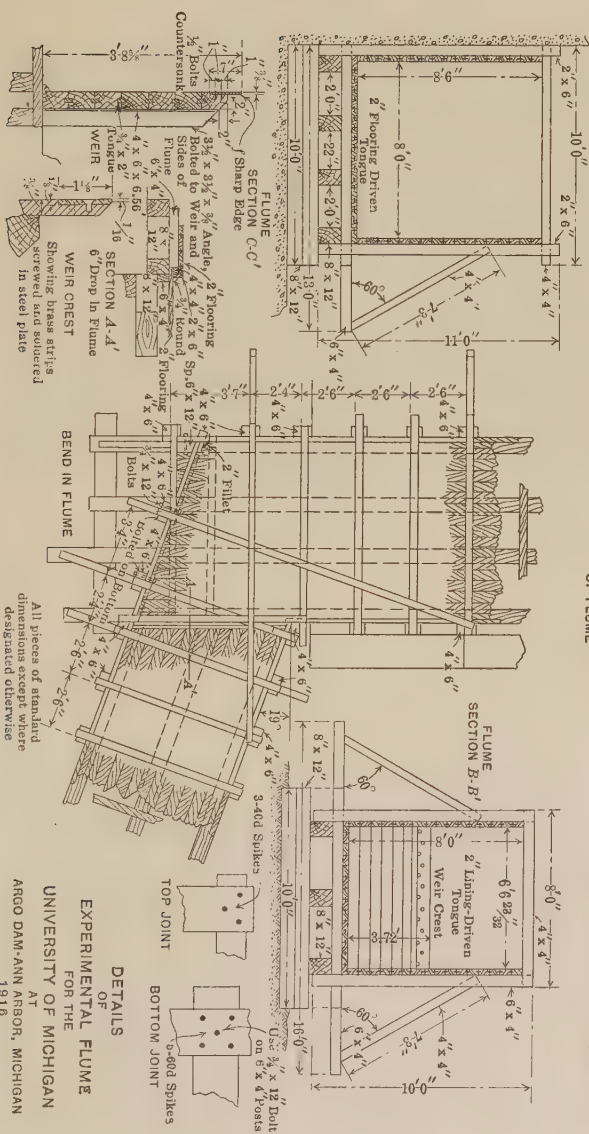


FIG. 4.

All pieces of standard dimensions except where designated otherwise

DETAILS
OF
EXPERIMENTAL FLUME
FOR THE
UNIVERSITY OF MICHIGAN
AT
ARGO DAM-ANN ARBOR, MICHIGAN
1916

Placing the weir at the end of the flume gave it a free basin about 90 ft. in length. The bottom of the flume was level throughout this entire length.

Fig. 10 shows the weir with about 0.3 ft. of water flowing over the crest.

Hook-Gauges and Piezometer.—For all heads up to 2 ft., the head on the weir was measured simultaneously by three hook-gauges operating in galvanized tanks connected to the flume by 2-in. pipes. These pipes were attached so that the opening was flush with the inside wall of the flume. Heads of from 2 to 4 ft. were measured by a fourth hook-gauge. A piezometer tube, with a $\frac{1}{4}$ -in. opening, flush with the side of the flume was also read as a check on the hook-gauge measurements.

Hook-gauge No. 1 was one of the new all-metal Gurley gauges, with a 45° point. The stilling tank for this gauge was connected to a point 6 ft. from the weir and 0.414 ft. below the weir crest. This was the point of observation used by Fteley and Stearns.

Hook-gauge No. 2 was one of the old Gurley gauges, with wooden slides and a sharp needle point. The stilling tank for this gauge was connected to a point 6 ft. from the weir and 6 in. above the bottom of the flume. This was the point of observation used by Francis.

Hook-gauge No. 3 was also one of the old Gurley gauges, with wooden slides, but it was equipped with a 45° point. The stilling tank for this gauge connected to points on both sides of the flume, 16.35 ft. from the weir and 6 in. above the floor of the flume. This was the point of observation used by Bazin.

Hook-gauge No. 4 was an all-metal hook-gauge designed especially for these experiments, and made by Eberbach and Son, of Ann Arbor, Mich.; it was found to be more satisfactory in its operation than any of the four gauges used. The stilling tank for this gauge connected with the lead pipes to Gauge No. 3.

The piezometer tube was $1\frac{1}{2}$ in. in diameter, with a brass scale, graduated to 0.005 ft., mounted at its side. The tube was connected with the flume at a point 11 ft. from the weir and 6 in. below the crest.

Each gauge was provided with an electric light on a drop cord in order to assist in the observation of the reflection at the point. Gauges with the 45° point were found to be the most readily observed.

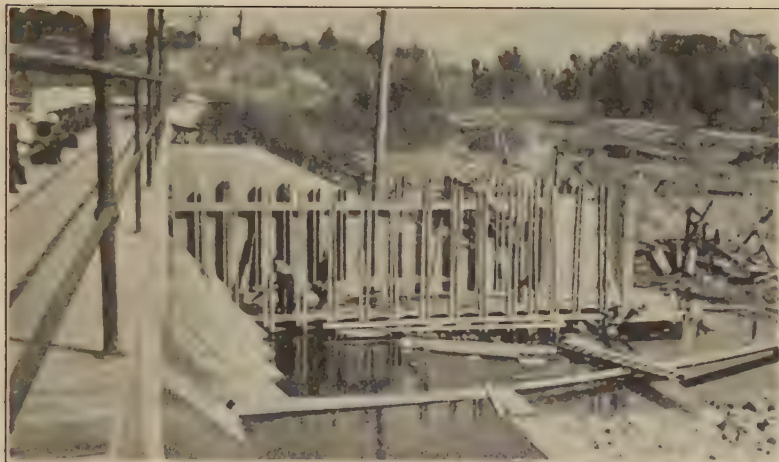


FIG. 5.—CONSTRUCTION OF FLUME.



FIG. 6.—CONSTRUCTION OF FLUME.



FIG. 7.—CONSTRUCTION OF FLUME.

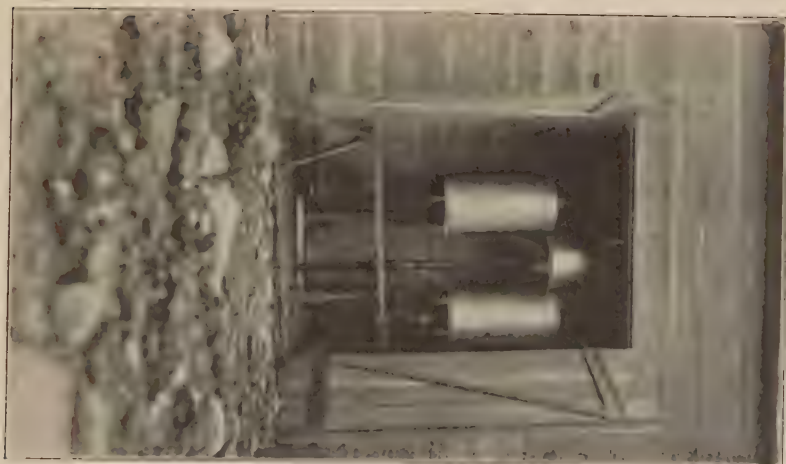


FIG. 8.—WEIR GATE IN FLUME.



FIG. 9.—THE ARGO TESTING FLUME.



FIG. 10.—THE WEIR.

All hook-gauges were mounted on a frame of 4 by 4-in. timbers. This frame was independent of the flume, having its foundation in a mass of concrete.

The gauges were enclosed within a gauge shelter for protection. Fig. 8 shows a little of the interior of this shelter, three of the galvanized stilling tanks being plainly visible.

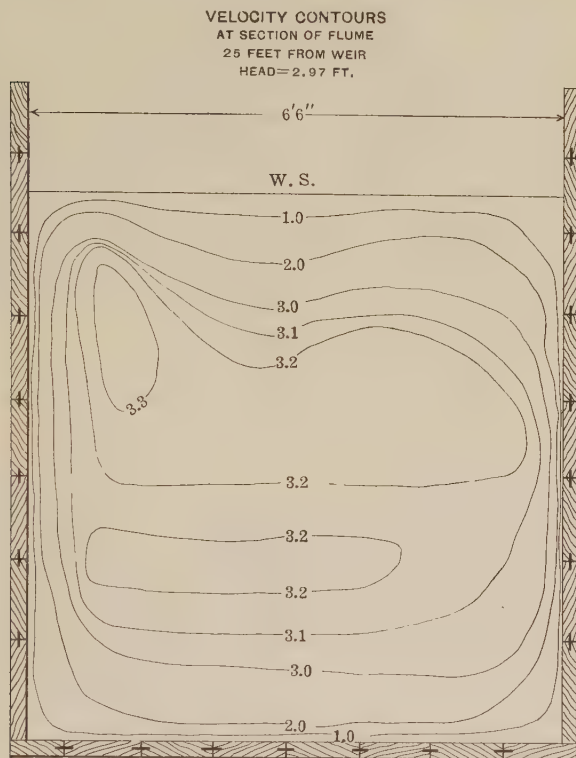


FIG. 11.

Dosing Apparatus.—In order to be able to measure a discharge over the weir as great as 200 cu. ft. per sec., by diluting a salt solution of a concentration of 300 grammes per liter, in the ratio of 6 000 to 1, during an experiment lasting 15 min., it was predetermined that a salt-solution tank with a capacity of about 50 cu. ft. would be required. This allowed 5 min. for dosing before and after each experiment, in order to insure good regulation of the dosing rate.

The solution tank is shown by Fig. 12. The tank was 4.067 by 3.33 ft. and 4 ft. deep. A piezometer was mounted on its side. The glass tube was 1 in. in diameter, and connected with the bottom of the tank. The height of the column of solution standing in the tube indicated the elevation of the solution in the tank. The gauge scale was made by Eberbach and Son. The scale had a sliding vernier

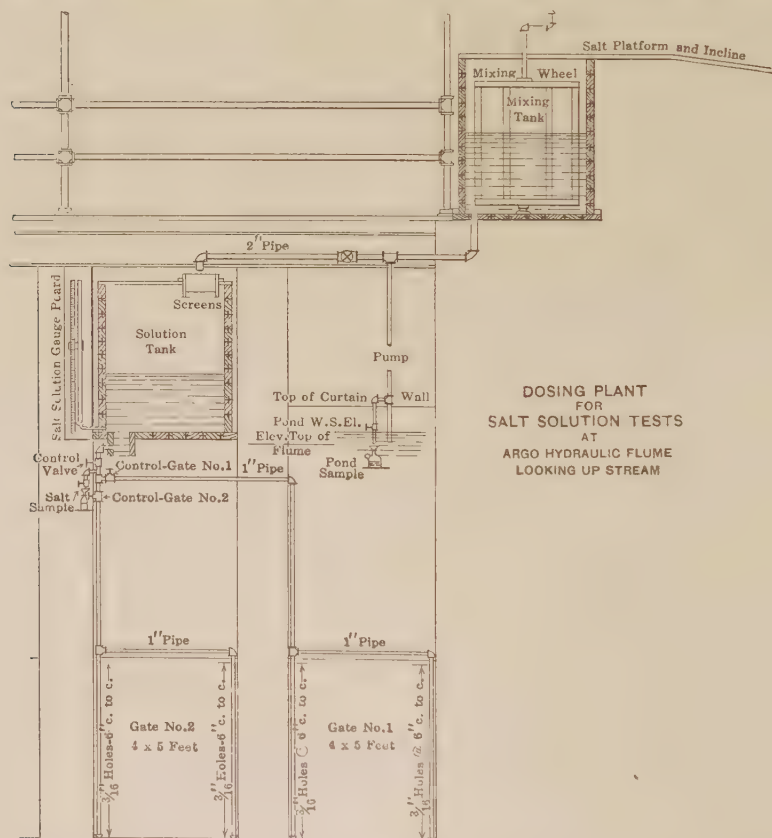


FIG. 12.

attached to a mirror index. It was possible to read the water-surface elevation within 0.001 ft. with this apparatus. Fig. 13 shows the location of the solution tank and gauge.

In varying the discharge of the water through the flume, from the least to the largest quantities, it was decided to use always the maximum quantity of salt solution which could be obtained from the

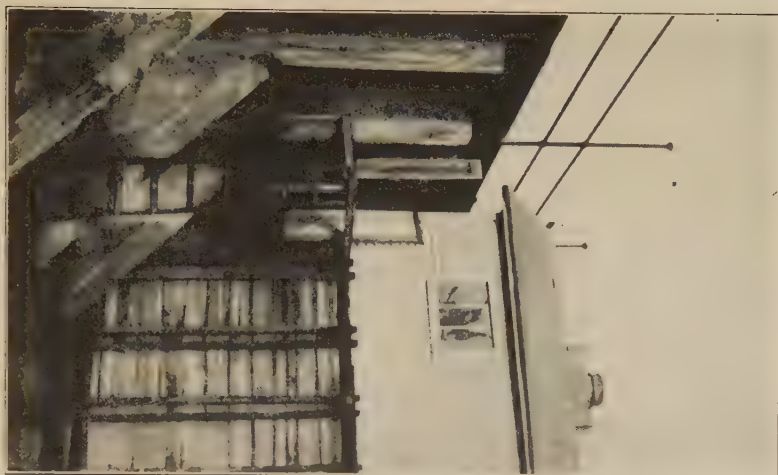


FIG. 13.—LOOKING TOWARD THE SOLUTION TANK AND PIEZOMETER.

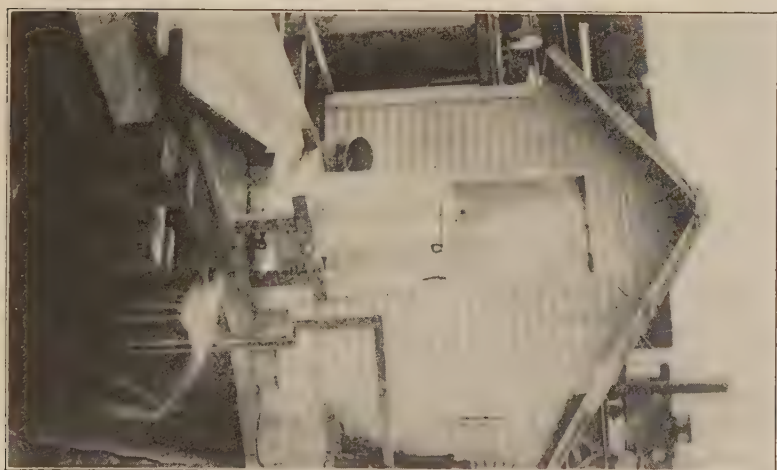


FIG. 14.—THE CALIBRATOR.

tank. This would insure a maximum difference between the initial and final readings of the piezometer, reducing to a minimum the effect of an error in the absolute reading of the piezometer scale. Hence, an endeavor was made to maintain q approximately the same for all experiments. Consequently, in order that the flume samples from all experiments might have the same concentration, it was necessary to vary the concentration of the salt solution for each experiment. The quantity of salt used varied from 1 000 lb. for the highest, to 15 lb. for the lowest, head.

Ordinary commercial salt was used. It was found to contain some foreign matter, including small chips and fine sand. This fact, combined with the requirement that no undissolved salt be present in the solution tank, necessitated first dissolving the salt in a mixing tank and then screening off all foreign matter before passing it into the solution tank. Screens of 30 and 80 meshes to the inch were used.

The mixing tank was filled with water by the pump indicated on Fig. 12. The solution of 1 000 lb. of salt was accomplished in only 40 min. with the aid of the mixing wheel inside the mixing tank.

The rate of dosing the salt solution was maintained constant throughout the entire experiment by a general control valve. Beyond this point, provision was made for drawing off a continuous sample of the salt solution through a small pipe tapping the larger discharge pipe. The salt solution could be introduced into Gate No. 1 or Gate No. 2 in any quantity desired, by the regulation of the valves in the pipes conducting it to them.

The salt solution was introduced into the orifice under the pressure head available due to the elevation of the solution tank. Distributing pipes, 1 in. in diameter, were fastened on each side of the orifice, and $\frac{3}{16}$ -in. holes, 6 in. from center to center, were drilled in these pipes at an angle of about 30° down stream. These distributing pipes, combined with the submerged weir and baffles, produced a very uniform distribution of the salt solution throughout the entire flume section.

Fig. 15 shows the general plan of the entire testing plant. The mixing tank and salt platform are in the foreground.

Sampling Apparatus.—The dosed flume-water samples were taken at a section 34.3 ft. above the weir, or 108.7 ft. from the point at which the salt solution was charged into the water.

With the flume sampling apparatus, Fig. 17, two to four samples of dosed flume water were obtained from 8 to 16 points in the flume section. Each of the inclined pipes had four $\frac{3}{64}$ -in. holes drilled in the upper side, 1.64 ft. apart. The discharge through each of these small orifices was "free" and practically the same throughout the length of the pipe. The water then flowed down the inclined pipe into the sample bottle at the left. The valve at the right provided means for flushing the pipe, the pet-cock above it remaining open when the pipe was not being flushed. An excess of the sample, above the predetermined rate of 1 gal. in 15 min., for which the pet-cocks at the left were set, flowed out of the pipe through the by-pass above the pet-cock. Under any head, this excess did not exceed the sampling rate.

A sample of the normal pond water was drawn from the suction pipe of the pump, as shown by Fig. 12.

Electric Bell and Salt Detection Apparatus.—There was a 5-volt battery circuit with electric bells at the solution tank and in the gauge shelter. These bells could be heard from any point on the flume. The ringing of the bells was controlled by a push-button in the laboratory.

A salt detection circuit was established in parallel with the bell circuit. The contact points, $\frac{1}{8}$ in. apart, were inside the flume, 3.5 ft. from the bottom, at the bend, at the sampling section, and at the Bazin gauging section. A milli-voltmeter in the laboratory was connected in this circuit so that it could be placed in series with any one set of contacts. With normal water flowing through the flume, the instrument registered 15 milli-volts; but when the dosed flume water reached the contacts, the pointer would swing slowly up to 19.5 milli-volts, the salt having increased the conductivity of the water. This instrument proved invaluable in determining the time interval required by the salt to travel from the point of dosing to that of sampling. From the indications of the milli-voltmeter, the "timer" could signal the sampler when the pointer showed that a uniform regime of salt dosing had been established.

Metal Calibrator.—A heavy galvanized-iron calibrator of 4.262 cu. ft. capacity, at 10.2° cent., was used in calibrating the solution tank. The calibrator had a conical bottom and top, reducing to a



FIG. 15.—THE FLUME AND SALT-SOLUTION APPARATUS.



FIG. 16.—THE EVAPORATION APPARATUS.

1½-in. pipe at each end. In principle, it was nothing more or less than a large pipette. Fig. 14 shows the calibrator standing in front of the laboratory, mounted on a wooden frame for convenient handling.

Chemical Laboratory.—A chemical laboratory, 8.5 by 18 ft., with sufficient equipment to make a salt solution analysis, was built on top of the flume near the spillway. Fig. 14 shows the entrance to the laboratory, and Fig 18 is a view of the inside, as seen from the door.

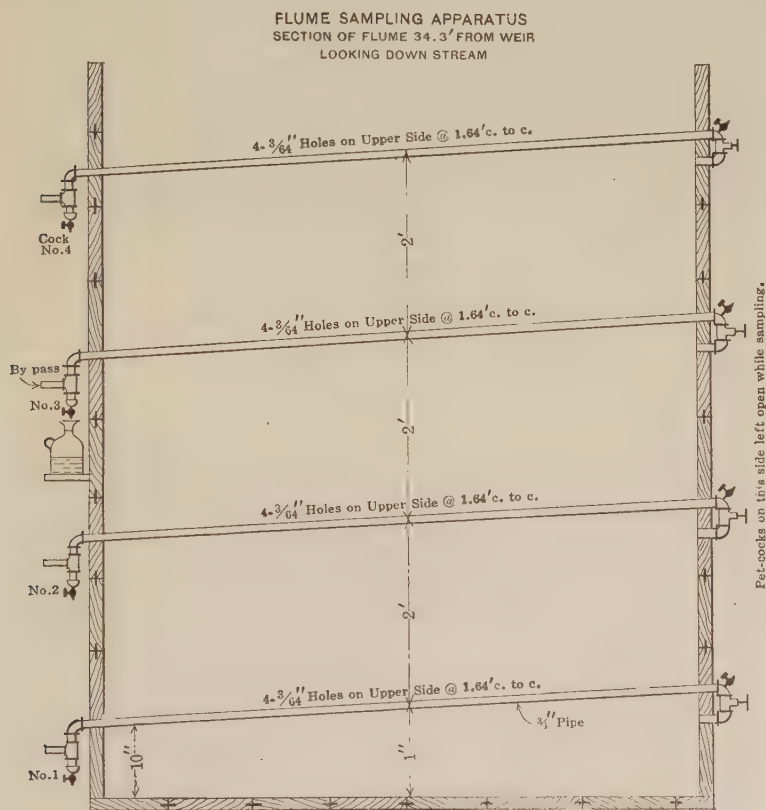


FIG. 17.

The following is a list of the essential apparatus in the laboratory:

- 1 balance with weights; sensitive to 0.1 mg.
- 1 Fairbanks scales, of 500 lb. capacity.
- 2 four-unit electric evaporators.
- 8 one-half liter separatory funnels.

- 4 100-cu. cm. burettes at 20° cent.
- 16 No. 3 casseroles.
- 3 one-liter volumetric flasks.
- 2 500-cu. cm. volumetric flasks.
- 1 100-cu. cm. volumetric flasks.
- 3 standard thermometers from 0° to 110° cent.
- 3 10-cu. cm. pipettes.
- 1 hydrometer.
- 12 one-liter flasks.
- 62 one-gallon spring-water bottles.
- 20 one-quart wide-mouth bottles.

Miscellaneous beakers, rubber stoppers, funnels, etc.

The separatory funnels, casseroles, and evaporators, as mounted during evaporation, are shown in Fig. 16. The evaporators were specially designed and manufactured for these experiments by Eberbach and Son. The heating coils were made of nichrome wire. By connecting a variable resistance in series with each unit, the heat under each casserole was regulated so as to keep the temperature of the sample just below the boiling point.

The experiments were performed so that the quantity of silver nitrate solution used in the titration of all samples would be either a little less or greater than 500 cu. cm. This required the use of 100-cu. cm. burettes, graduated to 0.1 cu. cm.

Spring-water bottles of 1-gal. capacity were used in obtaining the samples of the dosed flume water and the normal pond water. The salt sample was obtained in wide-mouthed 1-qt. bottles. When filled, all sample bottles were corked with rubber stoppers.

The hydrometer proved indispensable in checking the density of the salt solution in order to insure that all salt thrown into the mixing tank was dissolved before drawing the solution off into the solution tank.

The Fairbanks scales were used on top of the salt platform in weighing the salt to be dissolved.

Chemicals.—The chemicals used in the test were commercial salt, silver nitrate, and potassium bichromate.

A good grade of commercial salt was purchased at \$1.43 per bbl. In these experiments, 50 bbl. were used.



FIG. 18.—INTERIOR OF LABORATORY.



FIG. 19.—TAKING FLUME SAMPLES.

Silver nitrate was used as the reagent to detect the presence of the sodium chloride. A stock solution was made by dissolving 15 grammes of chemically pure silver nitrate in a liter of distilled water. This solution was kept in a dark-colored bottle in a dark closet in order to prevent action by light. This stock solution was diluted in the ratio of 10 to 1 in making the silver nitrate solution used in titration. This solution was also kept away from the light.

A potassium bichromate solution, having a concentration of 50 grammes per liter, was used to indicate the end point in the reaction of the silver nitrate on the sodium chloride. Only 6 or 7 drops of this solution were used for each titration. The indicator gives a lemon yellow color to the sample when the sodium chloride is in excess, turning to a light orange tint the instant the silver nitrate is in excess.

Hydrochloric acid proved indispensable in cleansing the casseroles after evaporation and titration. However, after cleansing, care was taken to wash away the last traces of the acid with distilled water before using the casserole for another evaporation.

Distilled water was obtained from the Chemical Laboratory of the University of Michigan. It was used in making the silver nitrate solutions, potassium bichromate solution, salt solution, sample dilutions, and in washing and cleansing the apparatus.

METHOD OF EXPERIMENTATION.

In the execution of a single experiment it was generally necessary to obtain data on the following quantities:

Salt Solution Gauging.—

- (1) Dosed flume water sample;
- (2) Normal pond water sample;
- (3) Average salt solution sample;
- (4) Average rate of dosing salt solution:
 - (a) Quantity of solution used,
 - (b) Duration of experiment;
- (5) Temperature of flume water and salt solution.

Weir Gauging.—

- (1) Average reading of the Fteley and Stearns Gauge;
- (2) Average reading of the Francis Hook-gauge;
- (3) Average reading of the Bazin Hook-gauge;
- (4) Average reading of the piezometer tube.

Subsequent Chemical Analysis.—

- (1) Temperatures and volumes of all solutions and samples handled in the laboratory;
- (2) Titration, in cubic centimeters of silver nitrate, of all samples.

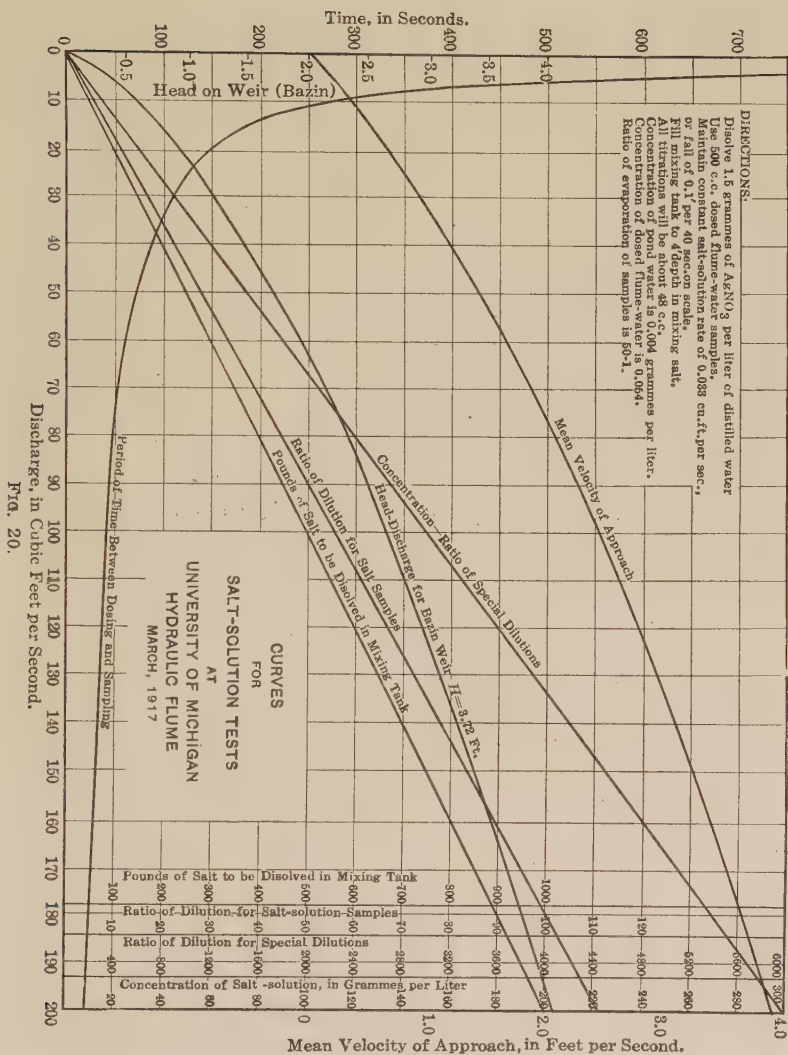
In order to obtain this information, it was necessary to obtain observers to act in the following capacities:

- (1) Supervising engineer,
- (2) Assistant engineer,
- (3) Salt solution gauge observer,
- (4) Dosing valve operator,
- (5) Recorder for dosing operation,
- (6) Pond sampler,
- (7) Timer,
- (8) Flume water sampler,
- (9) Observer at piezometer tube,
- (10) Observer at Hook-Gauge No. 1,
- (11) Observer at Hook-Gauge No. 2,
- (12) Observer at Hook-Gauge No. 3,
- (13) Chemist.

Duties of the Observers.—(1).—The duties of the supervising engineer were to outline and organize the work for the experiment, and then critically to observe its progress. By the curve sheet, Fig. 20, he knew the probable weir discharge and flume velocity for any given head on the weir. He advised the assistant engineer as to the number of pounds of salt required for the experiment, and also the specific gravity of the resultant salt solution. He advised the timer as to the probable time which it would take the salt to travel from the point of dosing to the point of sampling. He advised the chemist as to the ratio of dilution for the salt solution sample and the special dilutions.

(2).—The duties of the assistant engineer were to execute the experiment. He attended to the raising or lowering of the flood-gates, filling the mixing and solution tanks, and dissolving the salt. He took observations on the temperature of the flume water and salt solution; checked the timer on the duration of the experiment; and gave assistance to any observer in emergency.

(3).—The duties of the salt solution gauge observer were to note the readings of the piezometer tube, and thus maintain a constant rate



of dosing throughout the entire experiment. It had been predetermined that the solution in the tank should fall 0.1 ft. in 40 sec. The observer blew a whistle when the dosing was started. He held a stop-watch in each hand; then, advancing the vernier 0.1 ft. at a time, he started one stop-watch at the same time that he stopped the other, calling off to the recorder and the valve man the number of seconds which it took the solution in the tank to fall 0.1 ft. The valve man proceeded to regulate the control valve so as to obtain and maintain the predetermined rate of flow. After good regulation had been secured, he blew a whistle as the column in the tube passed the next 0.1-ft. mark, giving the recorder the scale reading at this point. He continued to give the recorder the time which it took the salt solution to descend each successive 0.1-ft. division on the scale. After the expiration of 15 min., he ended the experiment by blowing a third whistle as the solution in the tube passed the next 0.1-ft. mark, giving the recorder the final gauge reading. The dosing, however, was continued at the same constant rate until the solution tank was emptied.

(4).—The duty of the dosing valve operator was either to close or open the control valve so as to maintain the predetermined salt rate. He also secured two 1-qt. samples of the salt solution continuously during the experiment, taking care to flush both the bottles and lead pipe with the salt solution before sampling.

(5).—The duties of the recorder were to record the observations of the initial and final scale readings and the time intervals as given him by the solution gauge observer. He also held a stop-watch from which he obtained the total duration of the experiment, starting the watch at the second whistle and stopping at the third whistle. However, the stop-watch was not relied on entirely, as its reading was always checked by observing the second-hand on an ordinary watch.

(6).—The pond sampler secured 1 or 2 gal. of normal pond water from the siphon in the suction pipe of the pump during the progress of the experiment.

(7).—The timer occupied a position in the laboratory near the bell push-button, so that he could also see the milli-volt meter indicating the presence of salt. He recorded the time of the first whistle, notifying him that dosing had begun. He then observed the time interval before his milli-voltmeter indicated that salt had arrived in any strength at the sampling section. When the salt arrived at the

sampling section in full strength, he rang a long bell. He recorded the time of the second whistle denoting that uniform salt regulation had been attained. Allowing the same period of time after the second whistle as it took the salt to arrive at the sampling section in its prescribed strength after the first whistle, he started the gauge observers reading and the flume sampler sampling by ringing two short bells. Every 20 sec. after this, he rang one short bell, signaling a simultaneous reading of all the weir gauges. He recorded the time of the third whistle indicating that the official dosing had ceased. After a time interval had elapsed, since the third whistle, equal to the time interval which it took for the salt to arrive in any strength at all at the point of sampling after it had left the point of dosing, he finally signaled the flume sampler to cease taking samples and the weir gauge observers to take their final reading. This signal was three long bells. During the entire experiment, he watched the milli-voltmeter, noting any irregularities in its behavior. He checked the difference in time between the second and third whistles with the duration of the experiment obtained by the recorder and the assistant engineer.

(8).—The flume water sampler cleaned out his sampling pipes with compressed air before the experiment was started. This blew all scale and sediment away from the small $\frac{3}{64}$ -in. orifices. He then set the sampling pet-cocks so that the quantity discharged through them would fill a 1-gal. bottle in about 15 min. At the ringing of the long bell, he flushed out the sampling pipes and washed the sample bottles with the dosed flume water. He accomplished this as rapidly as possible and placed himself in readiness to start taking samples. He started the samples at the ringing of two short bells, finally withdrawing the bottles when three long bells signaled that the experiment had ceased. He immediately corked the sample bottles and carried them to the laboratory. Fig. 19 shows the sampler watching his samples during the progress of an experiment. The photograph was taken during high water, when the tail-water reached the elevation of the floor of the flume. This condition existed only for one week.

(9), (10), (11), and (12).—All weir gauge observers placed themselves in readiness to read their gauges at the ringing of the single long bell. When two short bells sounded, they took their initial reading, recording the time at which this reading was taken. They then continued to read their gauges every 20 sec., when a single short

bell signaled the reading. They took a final reading when the bell rang three successive times, recording this reading, and also the time at which it was taken.

(13).—The chemist had three classes of samples to analyze: the dosed flume water, the special dilutions, and the salt solution sample. The method of balanced evaporations required the dosed flume water and special dilutions to be evaporated and the salt solution samples to be diluted, so that final samples of similar volume of all three classes would require approximately the same quantity of silver nitrate solution in titration.

Flume samples were obtained from as many cocks as were submerged during the experiment. Three analyses were performed on each sample, to insure against error and contamination in the laboratory. As a rule, the three analyses agreed very closely and, in almost every instance, two of the three titrations checked within one-tenth of 1 per cent.

Of a flume sample, 500 cu. cm. were first measured in a volumetric flask, noting the temperature of the same. This was then discharged into a separatory funnel for evaporation. This evaporation was conducted over an electric evaporator at a temperature lower than the boiling point. An electric fan blowing the water vapors away from the casserole increased the rate of evaporation about 40 per cent. The entire 500-cu. cm. sample was evaporated until only about 10 cu. cm. remained in the casserole. Care was taken to wash the separatory funnel with distilled water and evaporate this with the rest. Each evaporation required about 7 hours, depending somewhat on the humidity of the atmosphere. The sample was then taken to the burette for titration. The initial reading of the burette was taken after the tube had been filled with silver nitrate solution to within a few cubic centimeters of the top. One drop of potassium bichromate solution was added to the initial sample, and an additional drop was added for every 10 cu. cm. of silver nitrate solution used in the titration of the sample. The silver nitrate solution was added at the rate of about 4 drops per sec., until within a few cubic centimeters of the end point of the reaction. In the meantime, a glass stirring rod was rinsed with distilled water. The final quantity of silver nitrate solution was admitted very slowly, at the rate of a drop in about 2 sec., until a point was reached where the former lemon yellow color of the

sample was permanently replaced by a very faint tint of orange. This being the end point sought, the burette reading was recorded. The difference between the initial and final reading, multiplied by 1 000 and divided by the actual volume, in cubic centimeters, discharged by the volumetric flask when the sample was measured for titration, gave the titration per liter of dosed flume water at the laboratory temperature.

The special dilutions were treated in a similar manner. Three dilutions were made for each experiment, in order to check the laboratory processes. The ratio for a given dilution approximated that which was obtained by dividing the weir discharge (computed by formula) by the salt rate, q . In some cases, this ratio could not be attained within several per cent. with the laboratory equipment at hand.

Each dilution was made by taking 10 cu. cm., as measured by a pipette, of the actual salt solution sample obtained during the experiment, and diluting it with the proper quantity of pond water obtained during the same test, until the prescribed ratio of dilution was obtained.

In almost every experiment it was necessary to make this dilution in two steps. For example, if a dilution in the ratio of 2 500 to 1 had been desired, it would have been made up as follows:

The contents of two 10-cu. cm. pipettes were discharged into a 500-cu. cm. volumetric flask, which had been washed previously with some of the pond water sample. The flask was then filled to the 500-cu. cm. mark with the pond water sample, and inverted forty times to secure a thorough mixture of the two solutions. The temperatures of both the salt solution and the pond water were recorded. This solution then had a ratio of dilution of approximately 25 to 1. The volume of one 10-cu. cm. pipette filled with this "stock" solution was discharged into a 1 000-cu. cm. of volumetric flask, which had previously been washed with some of the normal pond water sample. The flask was then filled with the normal pond water up to the 1 000-cu. cm. mark and thoroughly shaken to insure a good mixture of the two solutions. The temperature of both the stock solution and the pond sample were recorded. This mixture then had a nominal ratio of dilution of 2 500 to 1. A 500-cu. cm. sample of this dilution was measured and treated in the same manner as the dosed flume water samples.

All precautions and directions advised by Mr. Groat in his paper on "Chemi-Hydrometry" were followed strictly, in order to obtain accurate dilutions.

Dilutions of the salt solution sample with distilled water were made in a similar manner. The ratio of dilution for each experiment was obtained from Fig. 20. The contents of a 10-cu. cm. pipette filled with the dilute solution was discharged directly into a casserole, and titrated in the same manner as the other two classes of samples after evaporation.

From start to finish, the whole experiment progressed as follows:

(1).—The mixing tank was filled with water and the required quantity of salt dissolved in it.

(2).—The flood-gates were adjusted to secure the proper head on the weir.

(3).—The water in the solution tank, in order to keep it soaked, so that its volume would be constant, was discharged. The salt solution was then passed from the mixing tank into the solution tank by gravity.

(4).—The experiment was then ready to begin. The first long whistle announced that the dosing had started.

(5).—A long bell signaled the arrival of the salt at the sampling station. The flume sampler started to flush his pipes and bottles, and the weir gauge readers placed themselves in readiness to read their instruments.

(6).—The second whistle announced the fact that the prescribed uniform rate of dosing had been obtained, and that the experiment had officially begun at the dosing end. The salt solution sample and the pond sample were started at this time.

(7).—Two short bells signaled the flume sampler to take his flume samples, and the hook-gauge readers to take their initial readings.

(8).—Bells every 20 sec. signaled simultaneous readings on all the weir gauges.

(9).—In the meantime, the assistant engineer proceeded to take the temperature of the salt solution and the flume water.

(10).—A third whistle designated the end of the experiment at the dosing station. The valve man discontinued the salt sample.

(11).—Three bells signaled the final gauge readings. The dosed flume water samples were discontinued and carried to the laboratory.

(12).—The chemist then proceeded to analyze the samples.

Record Forms.—Fig. 21 displays the heads of the different forms of records used in recording the data obtained for these experiments.

CALIBRATIONS AND CORRECTIONS.

Stop-Watches.—The four stop-watches used in these tests were placed in the hands of a jeweler 2 months previous to the experiments, with instructions to operate and time them every day. When the experiments were started, all four watches were regulated within 1 sec. of error in 10 hours. However, subsequent regulation was found necessary, the stop-watches being timed each week during the progress of the experiments.

Two types of watches were represented: two continuous-running New England watches, and two Swiss speedway watches with cylinder movement. The New England watches gave much better satisfaction than either of the Swiss watches; but, in no experiment, was the stop-watch relied on absolutely in giving the duration of the test. The dosing recorder and also the timer kept accurate record of the time by observing the second-hand on an ordinary watch. This could be read within a second. In most experiments, the three watches checked each other within a second; in such cases the stop-watch record was used as the basis for computation.

Variation in Head on the Weir.—The experiments were performed at a period of comparatively high water in the Huron River. In no case did the pond elevation vary more than 0.05 ft. during the progress of the experiment. This insured a practically constant volume of water flowing through the flume.

The hook-gauge records, giving readings taken every 20 sec., show a maximum variation of head on the weir of 0.070 ft. for some high-head experiments. In these instances the water was traveling in the flume at a velocity exceeding 3.3 ft. per sec. With such a high velocity, the waves in the flume were of so great a magnitude that the floating railroad ties were ineffective in decreasing the amplitude of their motions. The variation decreases with a diminishing head on the weir, and, for heads below 3 ft., in no instance exceeds 0.025 ft. These variations are not due to a gradually increasing or diminishing head on the weir, but are either periodic or accidental.

The remarkable agreement between the mean readings for all three hook-gauges and the piezometer tube proves that "variation in head" was ineffective in producing error.

University of Michigan—Experimental Flume.
HOOK-GAUGE RECORD.

Observer _____ Date _____

Hook-Gauge Number _____ Correction of Datum _____

EXPERIMENT NUMBER.	TIME: Beg. and End	READING.	MEAN READING.	HEAD ON WEIR.

University of Michigan—Experimental Flume.
SOLUTION-TANK RECORD.

Observer _____ Date _____

EXPERIMENT NUMBER.	TIME: Beg. and End	SECONDS to Fall 0.1'	DURATION, Sec.	GAUGE READING.	DIFFERENCE.	VOLUME Cu. Ft.	RATE Cfs.

SPECIAL-DILUTION ANALYSIS.

EXPERIMENT NO.	STOCK DILUTION.							SAMPLE DILUTION.					ANALYSIS.				
	NOMINAL RATIO.	NO. OF VOL'S USED	FLASK NUMBER	PIPETTE, NO. OF VOL'S USED	PIPETTE NUMBER	TEMP. SALT SOLUTION	TEMP. POND SAMPLE	NO. DILUTION	NOMINAL RATIO	FLASK NO.	PIPETTE NO.	TEMP. STOCK SOLUTION	TEMP. POND WATER	EVAP. CO. NO.	FLASK NO.	TEMP. OF SAMPLE	TITRATION OF AgNO ₃

FLUME-WATER ANALYSIS.

DATE.	EXPER. NO.	SAMPLE NO.	EVAP. COIL NO.	FLASK NO.	TEMP. OF SAMPLE.	TITRATION.	MEAN TITRATION PER SAMPLE.	MEAN TITRATION FOR EXPER.

SALT-SOLUTION ANALYSIS.

DATE.	EXP. NO.	NOMINAL RATIO.	FLASK.		PIPETTE.		TEMP. SALT.	TEMP. H ₂ O	TEMP. STOCK.	PIPETTE NO.	TITRATION.
			VOL'S USED.	NO.	VOL'S USED.	NO.					

RECORD FORMS

FIG. 21.

Determination of the Width of the Weir Crest.—Table 1 gives the results of measurements of the width between the sides of the flume for different elevations above the weir crest. The value, for the width of crest, used in the computations, is tabulated in the last column. From top to bottom, these values do not differ more than 0.06 of 1 per cent.

TABLE 1.—WIDTH OF WEIR CREST.

Height above weir, in feet.	Width of flume, in feet.	Width of weir crest, in feet.
0.00	6.560	6.560
0.25	6.556	6.558
0.50	6.564	6.560
0.75	6.560	6.560
1.00	6.548	6.558
1.25	6.561	6.558
1.50	6.559	6.558
1.75	6.558	6.558
2.00	6.555	6.558
2.25	6.548	6.557
2.50	6.555	6.557
2.75	6.555	6.557
3.00	6.550	6.556
3.25	6.550	6.556
3.50	6.553	6.556
3.75	6.560	6.556
4.00	6.556	6.556

Determination of the Elevation of the Weir Crest Relative to the Gauges.—In order to determine the elevation of the weir crest relative to the weir gauges, the water in the flume was lowered a fraction of an inch below the crest of the weir. A hook-gauge was then placed inside the flume, 1 ft. from the weir. By using a level, the reading of this hook-gauge when the point of the hook was at the elevation of the weir crest was ascertained and recorded. This was tested and checked for several points along the crest. The hook was then lowered to the water level, and simultaneous readings were made on this hook-gauge and those in the gauge shelter. A relation was thus established between the gauges and the weir. Two such tests were made by different observers, the results checking within 0.0001 ft. Actual levels run between the weir and the gauges checked the foregoing results within 0.001 ft. The elevation of Gauge No. 4 was established by levels run between Gauges Nos. 2 and 3. Readings from this gauge can be relied on within 0.001 ft.

Uniformity of the Mixture of the Salt Solution with Normal Water.—Table 2 shows how thoroughly the salt solution became mixed with the pond water as it passed through the flume. The distribution of

TABLE 2.—TITRATION, IN CUBIC CENTIMETERS, OF Ag NO_3 SOLUTION REQUIRED TO NEUTRALIZE THE SALINE CONTENT OF 500-CU. CM. SAMPLES OF THE DOSED FLUME WATER.

Experiment No.	Head on weir.	SAMPLE COCK NUMBER:				Mean.
		1.	2.	3.	4.	
1.....	0.898	58.65	58.15	.....	.....	58.40
2.....	0.486	49.84	49.45	.....	.....	49.65
3.....	0.680	49.41	49.75	.....	.....	49.58
4.....	0.991	43.97	43.40	.....	.....	43.69
5.....	1.093	51.98	52.00	.....	.....	51.97
6.....	1.208	48.78	48.75	.....	.....	48.76
7.....	1.309	48.73	48.65	48.72	.....	48.70
8.....	1.379	.....	55.69	55.71	.....	55.70
9.....	1.569	.....	51.28	51.63	.....	51.46
10.....	1.772	51.71	51.24	52.00	.....	51.65
11.....	1.866	.....	.....	56.17	.....	56.17
12.....	1.964	.....	47.55	47.50	.....	47.53
13.....	2.286	52.60	52.81	52.79	.....	52.73
14.....	2.386	51.42	51.11	51.27	.....	51.27
15.....	2.690	50.77	50.75	50.44	.....	50.65
16.....	2.791	54.20	53.30	52.64	.....	53.34
17.....	2.895	46.45	46.47	47.07	.....	46.66
18.....	3.291	50.05	48.97	49.24	.....	49.42
19.....	3.266	52.40	(50.63)	50.63	50.95	51.15
20.....	3.344	52.69	51.83	51.95	65.86	55.58
21.....	3.574	51.40	52.99	(52.70)	52.40	52.37
22.....	3.757	56.90	52.45	51.66	52.43	53.36
23.....	3.934	48.73	50.77	50.79	51.17	50.39

the mixture depended somewhat on the manner in which the flood-gates were opened. Better distribution of the salt solution could hardly be desired for all experiments up to 3.344 ft. in head. For higher heads, it was found necessary to lower the submerged weir, in order to secure the higher discharges. The resulting mixture was not as good as in the previous experiments, but only in Experiment 20 was it exceptionally bad. The excess of salt in the sample obtained from Cock No. 4 in this experiment is difficult to explain, and tends to make it less reliable by far than the others.

Calibration of the Solution Tank.—The metal calibrator was calibrated gravimetrically at different temperatures.

Starting with an empty solution tank, the contents of the calibrator were emptied into the solution tank from the spillway platform above. The solution tank gauge readings before and after emptying were recorded. The calibrator was then refilled, and the process was repeated successively until the tank was full.

Two calibrations of the solution tank were made with water at different temperatures at two different times during the progress of the experiment. These calibrations checked within 0.1 of 1 per cent

A mean value of 1.374 cu. ft. for each 0.1 ft. of depth was used in all computations.

The solution tank was never left empty for any length of time, water being always maintained in the tank in order to insure constancy of volume. However, care was taken before each experiment to empty completely all the water from the tank and piezometer before admitting the salt solution. The tank was placed under the spillway platform and in this manner was protected at all times from the heat of the sun.

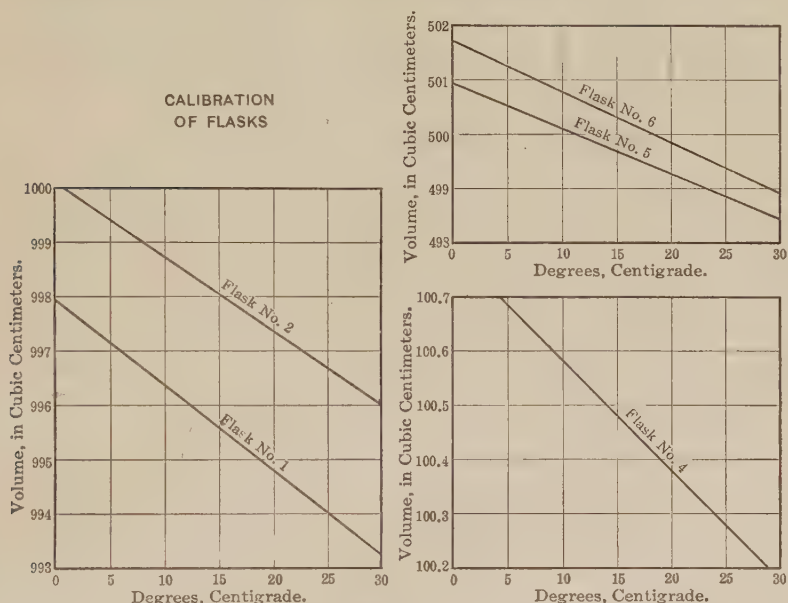


FIG. 22.

Calibration of Flasks and Pipettes.—The flasks and pipettes were carefully calibrated by R. A. Dodge, Teaching Assistant in Hydraulic Engineering, University of Michigan. Most of this work was conducted in the Physical Laboratories of the University, and the remainder on the balances at the flume.

The discharge volume of the pipettes was measured at different temperatures for different concentrations of salt solution. The flasks were calibrated at different temperatures only, using distilled water.

The results of these calibrations are represented graphically by the curves of Figs. 22 and 23. These curves were used in the final computations of the discharge by the salt solution method.

Low-Head Experiments.—For heads on the weir of less than 0.393 ft., with the apparatus at hand, it proved impossible to obtain reliable experiments, using the salt solution method. This was due to the fact that the mean flume velocity was less than 0.2 ft. per sec.; consequently, the mixing of the salt solution was poor, and the sprinkling system was not designed to meet the conditions present for so small a gate-opening.

COMPUTATION OF RESULTS.

Table 3, Plate I, gives the final computations on the data obtained in these experiments. Each step in the computation is made clear by the explanatory column at the left, designating the mathematical process involved.

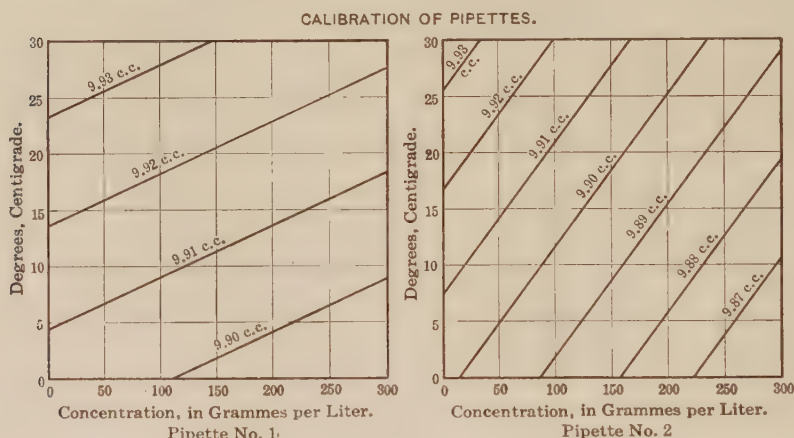


FIG. 23.

Computations were made in long hand. In general, they were carried out so that a change of one unit in the last significant figure produced a difference of less than 0.03 of 1% in the final result.

The Theisen, Scheel, and Diesselhorst tables for distilled water, and the Landolt and Börnstein tables for solutions of sodium chloride, were used in all computations. The Williams and Hazen hydraulic tables were used in checking the weir discharge, as computed by the Bazin formula.

The shrinkage coefficient, k , did not depart far enough from unity to change the value of the last significant figure in any of the experiments. It will be noted that it has been tabulated equal to 1.0, although, for some experiments, its actual value was 0.971.

PLATE I.
PAPERS, AM. SOC. C. E.
JANUARY, 1918.
NAGLER ON
VERIFICATION OF BAZIN
WEIR FORMULA.

TONS.

9	10	11	19	20	21	22	23
March 27.	March 28.	March 28.	May 2.	April 4.	April 5.	April 6.	April 7.
4.0	7.0	7.0	6.5	5.0	3.6	2.5	3.0
12.5	8.8	15.7	23.0	10.7	17.5	15.5	12.2
16.5	8.5	17.0	30.5	18.0	17.5	17.5	17.3
13.0	15.0	20.0	22.0	11.3	14.4	17.5	15.0
14.0	6.0	14.7	30.5	10.0	16.5	10.7	18.4
12.0	15.0	20.0	25.0	12.8	17.0	17.5	15.0
10.2	18.0	11.0	30.5	13.0	10.5	11.0	18.4
10.6	5.0	14.7	29.5	10.8	16.5	10.7	18.4
10.6	7.0	9.0	28.3	12.8	17.0	9.4	18.4
13.7	10.8	17.7	27.2	14.2	14.0	10.6	12.4
5.0	7.0	7.0	8.5	6.0	7.0	5.0	4.5
3	3	3	1	1	1	1	1
4	6	9	2	3	1	1	1
39.624	49.605	99.727	19.840	99.731	9.913	9.909	9.905
3	3.6	3	2.6	2.6	2	2	2
000.6	1 500.3	999.0	1 496.8	2 497.9	998.2	997.7	998.1
9.314	9.918	9.923	9.980	9.915	9.941	9.924	9.918
47.76	47.20	41.40	52.08	46.10	45.08	47.47	50.21
817	4 754	4 474	5 243	4 649	4 544	4 785	5 062
25.25	80.31	33.61	75.44	84.08	100.69	100.08	100.78
630	144 110	150 370	325 530	390 890	457 540	481 750	510 050
62.76	74.33	77.59	904.09	201.70	328.09	254.63	263.19
6.0	7.0	7.5	18.0	20.5	22.0	22.0	22.5
1.0454	1.0323	1.0361	1.1373	1.1380	1.1357	1.1713	1.1753
1.0436	1.0310	1.0338	1.1300	1.1357	1.1385	1.1355	1.1711
1.0410	1.0290	1.0335	1.1264	1.1261	1.1323	1.1275	1.1633
1.0432	1.0283	1.0561	1.1866	1.1378	1.1572	1.1703	1.1745
780	144 170	150 730	396 140	391 630	450 660	484 060	511 780
0.400	0.600	0.700	0.600	0.700	0.800	1.200	1.000
2.700	3.000	3.250	2.900	3.000	3.100	3.500	3.200
91.602	32.576	35.087	81.602	91.602	91.602	91.602	91.602
923.0	980.0	998.0	929.0	938.2	917.0	912.8	870.40
0.03427	0.03385	0.03511	0.03402	0.03518	0.03416	0.03462	0.03474
0.03438	0.03365	0.03511	0.03404	0.03519	0.03451	0.03465	0.03476
9.920	9.911	9.920	9.927	9.906	9.913	9.905	9.912
9.878	9.908	9.894	9.825	9.891	9.864	9.867	9.850
6	6	5.4	4	1	1	1	1
500.4	997.2	703.6	400.7	1 992.7	995.3	998.3	995.0
1.0007	1.0001	1.0008	1.0039	1.0002	1.0010	1.0004	1.0014
500.1	997.3	703.0	399.16	1 992.3	994.3	995.9	993.9
12.636	16.775	17.287	40.627	40.863	50.401	50.464	50.426
9.513	9.915	9.917	9.940	9.916	9.930	9.913	9.992
0.9997	0.9995	0.9997	0.9991	0.9994	0.9990	0.9996	0.9996
9.910	9.910	9.914	9.901	9.910	9.910	9.909	9.905
995.2	997.2	995.6	998.3	995.3	995.3	998.3	995.0
995.0	997.3	994.8	999.4	995.3	991.3	995.9	993.6
100.50	100.64	100.31	100.58	100.43	100.33	100.50	100.16
263.9	1 688.3	1 774.2	4 059.9	4 052.7	5 056.7	5 071.8	5 050.7
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
263.9	1 687.3	1 773.2	4 053.9	4 052.7	5 055.7	5 070.8	5 049.7
5	5	5	5	5	5	5	5
500.1	500.4	500.0	499.5	499.0	499.5	500.1	499.3
52.63	49.27	53.19	51.89	57.54	49.23	53.45	54.45
105.14	98.63	108.38	104.08	115.10	98.56	106.88	109.04
1.0003	1.0000	1.0003	1.0006	1.0006	1.0010	1.0002	1.0014
105.17	98.68	108.41	104.44	115.16	98.58	106.90	109.15
5	5	5	5	5	5	5	5
499.8	500.0	499.9	499.7	499.7	499.8	500.0	499.9
51.46	51.65	56.17	51.15	55.53	52.37	53.36	53.39
102.96	103.80	112.33	102.56	111.22	104.78	102.72	100.80
1.0007	1.0003	1.0004	1.0038	1.0007	1.0007	1.0004	1.0005
108.03	108.33	112.42	102.89	111.29	104.66	108.76	100.85
-2.14	+4.67	+6.01	-1.55	-8.87	+6.19	-0.14	-8.88
100	100	110	100	110	100	110	100
2 717.8	144 070	150 070	398 040	391 530	450 530	483 950	511 630
0.1223	+0.0547	+0.0708	-0.0153	-0.0402	+0.0681	-0.0014	-0.0632
0.9277	1.0547	1.0708	0.9943	0.9506	1.0081	0.9980	0.9173
1 297.8	1 599.8	1 650.4	4 120.10	4 222.4	4 722.4	5 077.9	5 022.0
44.42	63.84	58.14	140.39	148.49	163.35	175.85	191.25
0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.03
44.62	63.87	58.18	140.42	148.53	163.38	175.98	191.28
1.569	1.772	1.865	8.966	8.944	8.574	8.757	8.934
1.571	1.771	1.865					
1.672	1.776	1.869					
1.688			8.981	8.959	8.585	8.761	
44.66	63.68	58.35	141.69	147.81	163.69	177.56	191.47
-0.04	+0.04	-0.17	-1.27	+1.22	-0.51	-1.58	-0.19
-0.09	+0.03	-0.29	-0.90	+0.82	-0.81	-0.90	0.10

PROBABLE ERROR IN THE MEASUREMENT OF THE DISCHARGE BY THE
SALT SOLUTION GAUGINGS.

In every process of calibration, observation, and experimentation, it was sought to eliminate errors greater than 0.1 of 1 per cent. The reliability of the result for any experiment, therefore, is probably best indicated by the excellency of the distribution of the salt content of the differently dosed flume-water samples. This has been discussed, and is exhibited in Table 2.

There is no doubt that some experiments give the correct discharge within 0.1 of 1 per cent. In general, it might be said that the maximum variation from the true discharge is less than 0.6 of 1% for every experiment except No. 20. This may even be claimed for the experiments for which some of the samples are missing, due to the good distribution of the saline content for these discharges. The distribution of the salt in Experiment No. 20 is so bad that the resultant discharge can hardly be relied on within 2 per cent.

The arithmetical mean of the quantities of silver nitrate solution required to titrate the different samples was used as the value of the silver nitrate titration for the entire section. With the excellent salt and velocity distribution in most experiments, this introduced only a negligible error. In fact, due to the equal spacing of the sampling pipe perforations, the arithmetical mean was automatically taken in a horizontal direction; hence, it is doubtful whether the refinement of weighting the samples in a vertical direction is warranted.

Greater accuracy in the chemical gauging could have been attained, had it not been necessary to resort to the evaporation of the samples in making the chlorine analysis. However, the use of the direct method of analysis was prohibitive, for financial reasons, as it would have necessitated putting in a dosing apparatus of larger capacity and also the purchase of a much greater quantity of salt.

The silver nitrate solution used in the titration was as weak as it could be made and still produce accurate results; hence, further weakening of this reagent, in order to reduce the quantity of salt required in a "dosed water sample", was prohibitive. Although it is true that the experiments on the very lowest heads could have been performed with a saturated solution of salt in the existing apparatus, dosing at such a rate that the samples of dosed flume water would

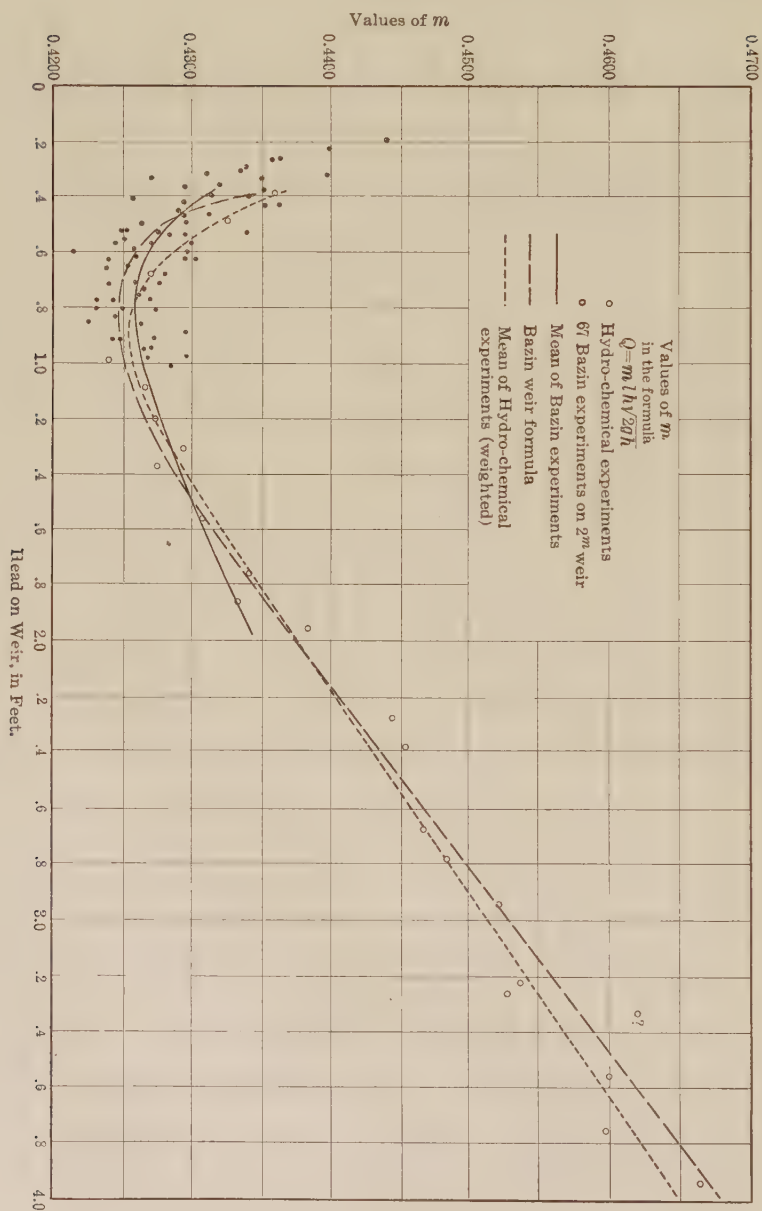


FIG. 24.

require no evaporation before analysis, this could hardly be done for heads in excess of 0.4 ft. on the weir.

The ratio of evaporation used was about 50 to 1; that of dilution was about 6 000 to 1. Direct analysis of the dosed sample, therefore, would require a dilution ratio of approximately 120 to 1, with the same concentration of salt solution for each experiment as was used in these tests. Had the solution tank been of fifty times the capacity of the existing tank, the experiment on the highest head (4 ft. on the weir) could have been executed so as to necessitate no evaporation of the dosed flume water samples; but it would have required the solution of at least 20 tons of salt for the single experiment. This would be about three times as much salt as was actually used in performing the entire set of experiments. As has been previously mentioned, 50 bbl. of salt were used in these tests, costing \$1.43 per bbl. Direct analysis would have required $50 \times 50 = 2\,500$ bbl., the cost of which is sufficient reason for resorting to evaporation at the sacrifice of a small degree of accuracy.

CONCLUSIONS.

Fig. 24 presents a graphical comparison of these experiments with those of Bazin on a similar weir, the Bazin experimental curve, and the Bazin formula. The weighted mean resulting curve of these experiments is shown by the dotted line. From this comparison, the following conclusions are evident:

(1).—For heads of less than 2 ft., the discharges, as given by the salt solution gaugings, are higher than those computed by the Bazin weir formula.

(2).—For heads greater than 2 ft., the Bazin formula gives discharges which are greater than those obtained in this set of experiments. This attains a maximum difference of 0.6 of 1% at a head of 4 ft. This fact is proved beyond doubt. In the future, engineers should make this correction in computations on high heads by the Bazin formula.

(3).—The salt solution experiments which lie within the range of the Bazin experiments, coincide with the Bazin formula and experimental curve more closely than the Bazin experiments themselves. The 67 experiments performed by Bazin on a weir 2 m. wide and 3.72 ft. high are shown by the small dots on Fig. 24.

(4).—The results of the high-head experiments fit the Bazin formula more closely than they would fit the probable extension of the Bazin experimental curve.

(5).—In claiming that the Bazin formula gives actual discharge within 1%, within the range of his experiments, this formula is all that its author maintains. There is, however, further merit for the Bazin formula, in that this statement proves to be valid for heads as high as 4 ft., on a weir 3.72 ft. high. The Bazin weir formula is thus extended 100% beyond its original legitimate field of application.

(6).—Table 3, Plate I, reveals the fact that simultaneous gauge readings on similar gauges, with similar taps, but applied at different points above the weir, do not differ by more than 0.005 ft. in extreme cases. In some experiments the readings even coincide, and, on the whole, there is no evidence of a tendency toward a definite positive or negative difference one from the other. Such differences as were actually observed might be attributed to accidental error and to the personal error of the different observers. Certainly the fact that the conducting pipe and tapping hole were 2 in. in diameter eliminated all error as to the nature of the tap.

The points at which these gauges tapped the flume duplicated the experimental points of observation used by Bazin, Fteley and Stearns, and Francis. Hence, these experiments seem to indicate that the discrepancies between the Bazin, Francis, and Fteley and Stearns formulas cannot be accounted for by the different points of observation used in their experiments. If the difference is due to the method of tapping, it must be accounted for in the nature of the tap rather than its location.

(7).—Finally, Table 4 presents a comparison between the results of these experiments and the following existing weir formulas:

$$\text{Bazin, } Q = \left(0.405 + \frac{0.00984}{H}\right) \left[1 + 0.55 \frac{h^2}{(p+h)^2}\right] L H \sqrt{2gH}.$$

$$\text{Fteley and Stearns, } Q = 3.31 L H^{\frac{3}{2}} + 0.007 L; H = h + 1.5 \frac{v^2}{2g}.$$

$$\text{Francis, } Q = 3.33 L \left[(D+h)^{\frac{3}{2}} - h^{\frac{3}{2}}\right].$$

$$\text{H. W. King, } Q = 3.34 \left(1 + 0.56 \frac{H^2}{(p+H)^2}\right) L H^{1.47}.$$

TABLE 4.—DISCHARGE PER FOOT OF WEIR CREST.

Head on weir.	CHEMICAL.	BAZIN.		BAZIN.		FTELEY AND STEARNS.		FRANCIS.		KING.	
	Experiment, in cubic feet per second.	Experiment, in cubic feet per second.	Percentage of error.	Formula, in cubic feet per second.	Percentage of error.	Formula, in cubic feet per second.	Percentage of error.	Formula, in cubic feet per second.	Percentage of error.	Formula, in cubic feet per second.	Percentage of error.
0.40	0.884	0.874	-1.13	0.876	-0.90	0.848	-4.07	0.845	-4.41	0.873	-1.24
0.60	1.599	1.591	-0.50	1.588	-0.69	1.557	-2.63	1.559	-2.50	1.593	-0.38
0.80	2.445	2.444	-0.04	2.437	-0.33	2.407	-1.56	2.401	-1.80	2.448	+0.12
1.00	3.416	3.423	+0.21	3.410	-0.18	3.370	-1.35	3.367	-1.44	3.424	+0.23
1.20	4.506	4.511	+0.11	4.499	-0.16	4.467	-0.87	4.442	-1.42	4.512	+0.13
1.40	5.709	5.706	-0.05	5.699	-0.18	5.661	-0.84	5.618	-1.59	5.705	-0.07
1.70	7.709	.....	.....	7.698	-0.14	7.650	-0.77	7.568	-1.83	7.698	-0.57
2.00	9.928	.....	.....	9.923	-0.05	9.865	-0.63	9.704	-2.26	9.896	-0.46
3.00	18.806	.....	.....	18.881	+0.40	18.806	0.00	18.160	-3.43	18.667	-0.24
4.00	29.833	.....	.....	30.006	+0.58	30.041	+0.10	28.416	-4.75	29.465	+0.68-1.17

The columns of Table 4 denoting the percentage of difference between these hydro-chemical gaugings and the other formulas, lead to the following conclusions:

(1).—The agreement with the Bazin experimental curve is remarkably good, except for the low heads.

(2).—The Bazin formula approximates these experiments within 1% for all discharges listed.

(3).—The Fteley and Stearns formula gives good results for the highest heads, but gives discharges too small for heads of less than 1 ft.

(4).—The Francis formula does not agree with these experiments. The discharges vary from 1.4 to 4.75%, and are lower than the hydro-chemical experiments, for both low and high heads on the weir.

(5).—The King weir formula approximates these experiments very closely for nearly all heads; in fact, it seems to fit the data better than any of the existing formulas, except for a divergence of 14% at the lowest head.

ACKNOWLEDGMENTS.

The writer is indebted to H. W. King, M. Am. Soc. C. E., Professor of Hydraulic Engineering, University of Michigan, for his assistance and co-operation in making these experiments possible. His interest in the experiments was a continual inspiration, and his suggestions were responsible for many improvements in the manner of conducting them. The writer also wishes to express his appreciation for the invaluable services of R. A. Dodge, Teaching Assistant in Hydraulic Engineering, University of Michigan. The paper by Mr. Groat on "Chemi-Hydrometry" was a constant source of reference in the execution of these experiments. Having used the methods described in this paper very freely, the writer wishes to acknowledge his indebtedness to Mr. Groat. For assistance in the operation of the experiments, the writer wishes to thank Mr. C. O. Wisler, Instructor in Civil Engineering, University of Michigan, and the following senior and graduate civil engineering students at that University in 1917: Messrs. O. B. Apeseche, C. E. Gill, E. R. MacLaughlin, S. P. Davis, T. G. Bedford, G. A. Covarrubias, J. B. Jewell, H. J. McFarlan, E. Gusman, T. B. Dimmick, A. H. Cohn, A. B. Pastor, J. W. Van Brunt, C. E. Wells, M. F. Wagnitz, J. B. Franks, G. A. Pomeroy, and A. Marino.

